

**Deepwater Program: Exploration and Research of Northern Gulf of Mexico
Deepwater Natural and Artificial Hard Bottom Habitats with Emphasis on Coral
Communities: Reefs, Rigs and Wrecks**

Project Director - James Brooks

TDI-Brooks International, 1902 Pinon, College Station, TX 77845

Phone: (979) 693-3446 FAX: (979) 693-6389 E-mail: Drjmbrooks@aol.com

CO-PI Chuck Fisher

208 Mueller Laboratory, The Pennsylvania State University, University Park, PA 16802

Phone: (814) 865-3365 FAX: (814) 865-9131 E-mail: cfisher@psu.edu

CO-PI Harry Roberts

CSI-LSU, 304 Howe-Russell Geosciences Complex, Baton Rouge, LA 70803

Phone: 225.578-2964 FAX: 225-578-2520 E-mail: hrober3@lsu.edu

CO-PI Dan Warren

C&C Technologies, Inc, 730 E. Kaliste Saloom Rd., Lafayette, LA 70508

Phone: 337-261-0660 E-mail: robert.church@cctechnol.com

CO-PI Ian MacDonald

TAMUCC, 6300 Ocean Dr. ST320, Corpus Christi, TX 78412

Phone: 361.825-2234 FAX: (361) 825-2742 E-mail: imacdonald@falcon.tamucc.edu

CO-PI Erik Cordes

313 Biology-Life Sciences, 1900 N. 12th Street, Temple University, Philadelphia, PA 19122

Phone: 215-204-8854 FAX: 215-204-6646 E-mail: erik.cordes@temple.edu

CO-PI Chris German

Woods Hole Oceanographic Institution, Clark South 276, MS#24, Woods Hole, MA 02543

Phone: 508 289 2853 FAX: E-mail: cgerman@whoi.edu

CO-PI Liz Goehring

The Pennsylvania State University, 208 Mueller Laboratory, University Park PA 16802-5301

Phone: (814) 863-0278 FAX: (814) 865-9131 E-mail: exg15@psu.edu

CO-PI Bernie Bernard

TDI-Brooks International, 1902 Pinon, College Station, TX 77845

Phone: 979.690-6287 FAX: (979) 693-6389 E-mail: berniebernard@tdi-bi.com

CO-PI Gary Wolff

TDI-Brooks International, 1902 Pinon, College Station, TX 77845

Phone: 979.846-7679 FAX: (979) 693-6389 E-mail: garywolff@geodatapub.com

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LONG-TERM GOALS

A primary goal of this study is to obtain a robust predictive capability for the occurrence of rich cnidarian (primarily scleractinian coral) hard ground communities in the deep Gulf of Mexico. To achieve this long-term goal, this study will accomplish three interrelated and interdependent objectives

OBJECTIVES

A primary goal of this study is to obtain a robust predictive capability for the occurrence of rich cnidarian (primarily scleractinian coral) hard ground communities in the deep Gulf of Mexico. To achieve this long-term goal, this study will accomplish three interrelated and interdependent objectives:

- 1) Discover and describe new locations at greater than 300m depth in the GoM with extensive coral community development, particularly including *Lophelia pertusa*.
- 2) Gain a more comprehensive understanding of the fundamental processes that control the occurrence and distribution of *Lophelia* and other extensive coral communities at depths greater than 300 m in the GoM through both laboratory experiments and field data collection.
- 3) Document and understand the relations between coral communities on artificial and natural substrates with respect to community composition and function, phylogeographic and population genetics, and growth rates of the key cnidarian foundation fauna.

Upon meeting these three interrelated objectives we will have obtained an understanding of the biology and biogeography of *Lophelia* in the GoM that will result in a quantum increase on our ability to predict the occurrence of *Lophelia* at additional sites based on data such as bathymetry, current models, 3D seismic profiles, and known occurrence of source populations.

APPROACH AND WORK PLAN

In order to meet the objectives outlined above, the following scientific and technical plan is being implemented.

Key individuals participating in this work and their roles are: Dr. James Brooks is the Project Manager and leads in administration of this project. Dr. Charles Fisher (Pennsylvania State University) coordinates the biological studies and interface with the USGS teams and the geological and oceanographic studies. His research group will take responsibility for quantitative physical and photographic collections, community composition and structure analyses, and trophic studies of the endemic and other closely associated seep and coral fauna. Dr. Harry Roberts (Louisiana State University) coordinates the geological/geophysical and oceanographic studies. He develops site selection for exploration of potential new natural deep coral communities and also coordinate the geological and oceanographic deployments and studies. His colleague, Dr. Susan Welsh develops and runs a very high resolution numerical circulation model of the Gulf of Mexico that is used to identify the likely geographic areas and depth ranges for recruitment of *L. pertusa* larvae on the northern slope and compute dispersal kernel trajectories and dispersion of coral larvae by oceanographic current. Dr.

Erik Cordes (Temple University) is responsible for the live *Lophelia pertusa* experiments, gorgonian genetics, and coordinate the phylogeography and taxonomy team. He also works with Fisher's team on studies of coral communities and be responsible for coordination with other outside taxonomic experts. Dr. Ian MacDonald directs the use of digital imagery in the initial site survey and recon cruise, contributes to the site selection process, oversees the use of transect imagery for site descriptions and contributions to faunal inventory, and the deployment and analyses of the time lapse cameras and imagery and the Fisheries review in Year 1 of the project. Dr. Chris German leads on deployments of the time series sediment traps and oversees the integrated analyses of the samples. Dr. William Schroeder assists in the analysis of coral communities on rigs and wrecks and also participates in the over-all study synthesis phase. Mr. Dan Warren and Mr. Rob Church from C&C Technology coordinate the wrecks studies. Dr. Chris German (WHOI) coordinates the time series sediment trap studies, and Ms. Liz Goehring (Penn State and NSF Ridge 2000 office) coordinates the education and outreach activities. Dr. Bernie Bernard, TDI-Brooks Director and Chief Technology Officer coordinates navigation and logistics. Dr. Gary Wolff is project Data Manager and Ms. Suzanne Cardwell is financial and project administrative support.

Dr. Tim Shank conducts studies on the population genetics of several coral associated taxa. Dr. Iliana Baums oversees development of molecular markers for studies of population connectivity in antipatharians and the construction of live *Lophelia* maintenance aquaria. Dr. Stephen Cairns identifies the hard coral samples collected. Peter Etnoyer oversees the classical taxonomy of octocorals and Dr. Dennis Opresko the classical taxonomy and phylogeography of antipatharians. Dr. Roy Cullimore, and Lori Johnston (Droycon Bioconcepts Inc. of Regina Canada) - deterioration rate, preservation and stability of the wreck sites. Dr. Sheli Smith (PAST Foundation) - eighteenth and nineteenth century marine architecture, Dr. Christina A. Kellogg, USGS, microbiology

In addition to this core team we have assembled an international team of collaborators that significantly expands our taxonomic expertise.

Anders Waren (Swedish Museum of Natural History) - Limpets and snails

Dr. Stéphane Hourdez (Station Biologique de Roscoff, France) - polychaete

Dr. Daphne Fautin (University of Kansas) - sea anemones

Dr. Sabine Stohr (Swedish Museum of Natural History)- ophiuroids

Maria Pia Miglietta (Penn State University) – hydroids

WORK COMPLETED

Three cruises have been completed on the *Lophelia* II project. Cruise 1 was conducted on the NOAA Ship research vessel ***Nancy Foster*** from September 2, 2008 to October 2, 2008.. The cruise mobilized and embarked from Galveston, Texas and returned to Gulfport, Mississippi for the second leg. The second leg concluded on 2 October 2008 and demobilized in Pascagoula, Mississippi. Cruise 2 was conducted on the TDI-BI Ship ***RV Brooks McCall*** from **17 June – 1 July**, 2009. The cruise mobilized and embarked from Freeport, Texas and demobilized in Gulfport, Mississippi. Cruise 3 was conducted on the NOAA Ship ***Ronald H. Brown*** from 19 August – 12 September 2009. The cruise mobilized in Key West, Florida. One mid-cruise personnel transfer took place on 5 September. The cruise demobilized in Pensacola, Florida on 12 September 2009.

RESULTS

Cruise1 Leg1 - The Ewing Banks Wreck site was confirmed to be a historic shipwreck site, which likely dates to the nineteenth century. More *Lophelia* was discovered growing on that site than any other nineteenth century wooden wreck known in the Gulf of Mexico. Many of the wreck's attributes, such as the lack of cargo, rigging, or machinery, make it an intriguing mystery. The identity of *Gulfoil* was confirmed on a brief dive at the site and substantial coral colonies were documented. The preliminary examination suggests the *Lophelia* coverage at *Gulfoil* may be more substantial than that documented at *Gulfpenn* in 2004. The dive on *Gulfpenn* allowed the identification of the stern section of the tanker, the microbial experiment placed on the site in 2004 was reexamined, and a temperature logger was placed on *Gulfpenn*'s bow.

Cruise1 Leg2 - During the 12 working days at sea, multibeam data was collected at 13 sites and 10 lowerings of the ROV were completed over 8 different sites. There were two ROV operations days lost to weather conditions, one dive never reached the bottom, and three other dives were ended with under two hours of bottom time due to technical problems with the ROV. During almost every dive the manipulator failed, and this severely limited the capacity to collect physical samples for future genetics work. On most of the latter dives, only one attempt was made to collect samples in areas of high coral diversity and density due to the anticipation of manipulator failure and the extremely long amount of time required to sample (1-5 samples obtained in 1-3 hours).

Cruise 2 –

Surveys were completed using WHOI's AUV *Sentry* at targeted features in the following MMS lease blocks: GB837, GB535, GC600, GC 246, MC885, MC657 and VK826.

Cruise 3 – UWHOI's ROV *Jason II* was used to: explore 4-6 new sites for the occurrence of deep water coral reefs; make collections of *Lophelia* and other corals for genetic and physiological studies; make collections of communities associated with *Lophelia* and other corals for ecological studies; collect quantitative digital imagery for characterization of sites and coral communities; collect spatially explicit physical near bottom oceanographic data; deploy cameras and microbial arrays; reposition larval traps and current meters; collect push cores; and conduct a series of linked archeological/biological investigations on deep water shipwrecks. In addition to launching and recovering *Jason II*, elevators were deployed and recovered approximately six times, four moorings (2 larval traps and 2 current meters) were deployed, and CTD casts were conducted.

Completed 17 dives at 13 natural sites, eight of which had never had visual surveys before. Even with this high degree of pure exploration, corals were found at every site, and new high-density *Lophelia pertusa* communities at three of the sites. These included Garden Banks 535, the western-most *Lophelia* site in the Gulf; Viosca Knoll 906, one of the largest continuous *Lophelia* reefs known in the Gulf and named Roberts' Reef; and a new area of Viosca Knoll 826, a 200 m long ridge hosting a large *Lophelia* reef. At Mississippi Canyon 751, the most active seep known to host live *Lophelia* colonies was investigated. Some high density black coral communities were found at a number of the sites investigated, and a new site with a high abundance of bamboo corals at the northern end of the Florida Escarpment. This site in DeSoto Canyon was a new depth record for six different genera of octocorals including three different species of bamboo corals. The first alkalinity data from the deep Gulf of Mexico was collected, which will guide research into the potential impact of ocean acidification on deep-water corals throughout the rest of the project.

A total of five historic shipwreck sites were investigated, one of which had never had been surveyed by ROV before. The wrecks included 4 metal-sheathed wooden sailing vessels (VK wreck, 7,000' wreck, EW Bank wreck, GC245 wreck) and 1 World War II U-boat casualty (*Gulfpenn*). One of these wrecks, the 7,000 ft wreck, represents the deepest known shipwreck site in the Gulf of Mexico. Investigations at the wooden wrecks detailed them with video and still imagery and placed long and short-term microbiological experiments for corrosion studies. The survey of the *Gulfpenn* was carried out primarily to further document the extensive growths of *Lophelia* corals at the site. Archaeological investigations were limited since this wreck was studied extensively during the 2004 Deep Wrecks I Project. The four metal-sheathed wooden sailing vessels represent not only a cross-section of 19th and early 20th century wooden shipbuilding technology, but their locations and various depths provide a unique opportunity to examine site formation and distribution processes in the Gulf of Mexico's deepwater areas. The study of these site formation and distribution processes will help refine the shipwreck avoidance criteria model developed during the 2004 Deep Wrecks I Project.

IMPACT AND APPLICATIONS

National Security

This program will provide critical information on the exploration, characterization and function of hardground communities to MMS. As manager of the nation's seafloor mineral resources, MMS will use this information to aid in the development of critical energy resources, which may affect domestic energy production.

Economic Development

Increased energy and mineral production will have a positive economic impact at numerous levels in industry.

Quality of Life

Information on the location and functioning of hardground communities gathered by this program will have a positive impact on other ocean users, the natural environment, and the human environment. It will aid in minimizing the environmental impact on sensitive habitat and mitigate any potential damage to these communities.

Science Education and Communication

As a NOAA Ocean Explorer "Signature Expedition," the *Lophelia II* cruise was featured on the NOAA Ocean Explorer website (<http://oceanexplorer.noaa.gov/welcome.html>) and promoted through NOAA OE channels (e.g., VIMS Scuttlebutt listserve). During the cruise, log entries, seafloor and shipboard imagery and seafloor video clips were posted to the NOAA OE site on almost a daily basis. Log entries were authored by various cruise participants as an opportunity to feature individual contributions to the overall research agenda. A Highlights "Best Of" Imagery and Video DVD was also created and provided to NOAA OE.

TRANSITIONS

Data is provided to the ChEss database, which is a component of the Census of Marine Life (CoML) Ocean Biogeographic Information System (OBIS) data base. This work will contribute significantly to the goals of the Atlantic Equatorial Belt studies of the ChEss program, particularly the components that will allow interpretation of our findings in the context of hardground habitats around the world.

RELATED PROJECTS

- Chemosynthetic Ecosystems Study (MMS Report 95-0021). <http://www.gomr.mms.gov/homepg/regulate/envIRON/studies/1995/95-0021%20Vol%20I.pdf>.
- Stability and Change in Gulf of Mexico Chemosynthetic Communities (MMS Report 2002-036). <http://www.gomr.mms.gov/homepg/regulate/envIRON/studies/2002-036.pdf>.
- The Deepwater Program: Northern Gulf of Mexico Continental Slope Habitat and Benthic Ecology (MMS contract 1435-01-99-CT-30991).
- Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico. (Award Number: 1435-01-05-39187) <http://tdi-bi.com/chemo3/chemo-main.htm>
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Figure 1. Mosaic of *Lophelia* colonies growing on the rails and superstructure of the *Gulfpenn*.



Figure 2. A view of the copper sheathing on the VK Wreck's port side hull.

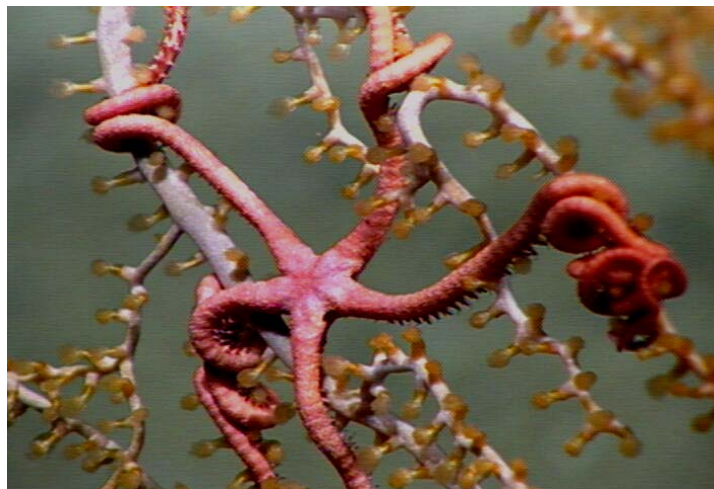


Figure 3. Paramuricid hosting a single *Asteroschema* ophiuroid.

REFERENCES

- Aloisi, G., I. Bouloubassi, S.K. Heijs, R.D. Pancost, C. Pierre, J.S.S. Damste, J.C. Gottschal, L.J. Forney and J.M. Rouchy, 2002, CH₄-consuming microorganisms and the formation of carbonate crusts at cold seeps: Earth and Planetary Science Letters, v. 203, p. 195-203.
- Andrews A.H., E.E. Cordes, M.M. Mahoney, K. Munk, K.H. Coale, G.M. Cailliet, J. Heifetz. 2002. Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. Hydrobiologia 471: 101-110.
- Barnette, M. C. 2001. A review of the fishing gear utilized within the Southeast Region and their potential impacts on essential fish habitat. NOAA Tech. Memo. NMFSEFSC- 449. 62 pp.
- Barnette, M. C. 2006. Observations of the Deep-Water Coral *Oculina varicosa* in the Gulf of Mexico
- Baums IB, Hughes CR, Hellberg MH (2005a) Mendelian microsatellite loci for the Caribbean coral *Acropora palmata*. *Marine Ecology - Progress Series* **288**, 115-127.
- Baums IB, Miller MW, Hellberg ME (2005b) Regionally isolated populations of an imperiled Caribbean coral, *Acropora palmata*. *Molecular Ecology* **14**, 1377-1390.
- Baums IB, Paris CB, Cherubin LM (2006) A bio-oceanographic filter to larval dispersal in a reef-building coral. *Limnology and Oceanography* **51**, 1969-1981.
- Bayer, FM (1956) Octocorallia. In: Moore, RC (ed) Treatise on invertebrate paleontology. Part F, Coelenterata. University of Kansas Press, Lawrence, Kansas, p 166-231
- Berman, Bruce D. 1971. *Encyclopedia of American Shipwrecks*. Boston: Mariners Press.
- Bergquist, D. C., I. A. Urcuyo, and C. R. Fisher. 2002. Establishment and persistence of seep vestimentiferan aggregations from the upper Louisiana slope of the Gulf of Mexico. Mar. Ecol. Prog. Ser. 241: 89-98.
- Bett BJ (1997) Atlantic Margin Environmental Survey: Seabed Survey of the Shelf Edge and Slope west of Shetland. Published by Challenger Division for Seafloor Processes: Southampton Oceanography Centre, NERC/ University of Southampton., pp. 165.
- Bett B.J. (2001). UK Atlantic margin environmental survey: introduction and overview of bathyal benthic ecology. *Cont. Shelf Res.* 21: 917-956.
- Browning, Robert M., Jr. 1996. U.S. Merchant Vessel War Casualties of World War II. Naval Institute Press. Annapolis.
- Burch, H. A. 1942a. Summary of Statements by Survivors of the SS *Gulf Penn*, U.S. Tanker. Navy department, Office of the Chief of Naval Operations. May 22. NOAA Technical Memorandum NMFS-SEFSC-535. 12 pp.
- Cairns, SD (1977) Guide to the commoner shallow water gorgonians (sea whips and sea fans) of Florida, the Gulf of Mexico, and the Caribbean. Sea Grant Field Guide Ser. No. 6

- Cairns S.D. (1978). A checklist of the ahermatypic scleractinia of the Gulf of Mexico, with the description of a new species. *Gulf Res. Rep.* 6: 9-15.
- Cairns S.D. (2001). A brief history of taxonomic research on azooxanthellate Scleractinia (Cnidaria: Anthozoa). *Bull. Biol. Soc. Wash.* 10: 191-203.
- Cairns S.D., D.M. Opresko, T.S. Hopkins & W.W. Schroeder. (1993). New records of deep-water Cnidaria (Scleractinia & Antipatharia) from the Gulf of Mexico. *Northeast Gulf Sci.* 13:1-11.
- Childress, J.J. and T.J. Mickel. 1980. A motion compensated shipboard precision balance system. *Deep-Sea Res.* 27: 965-970.
- Church, R.A. 2003. Archaeological assessment for a proposed 6-inch gas and 6-inch oil pipeline routes from Block 962 to Block 786, Viosca Knoll Area. Prepared by C & C Technologies, Inc. for Geoscience Earth & Marine Services, Inc. on behalf of Mariner Energy. Report submitted to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Church, R., D. Warren, R. Cullimore, L. Johnston, W. Schroeder, W. Patterson, T. Shirley, M. Kilgour, N. Morris, and J. Moore. 2007. Archaeological and biological analysis of World War II shipwrecks in the Gulf of Mexico: Artificial reef effect in deep water. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2007-015.
- Church, Robert. 2004. "Shipwreck and Sonar Contact ROV Investigation, Blocks 245 and 329, Green Canyon Area." Prepared by C & C Technologies, Inc. for GulfTerra Energy Partners, L.P. Report submitted to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Church, R.A. and D.J. Warren. 2008. Viosca Knoll Wreck: Discovery and investigation of an early nineteenth-century sailing ship in 2,000 feet of water. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-018.
- Church, Robert and Lynn Samuel. 2004. Archaeological, Engineering and Hazard Study for a Proposed 16-inch Oil Export Pipeline from Block 680, Green Canyon Area to Block 332, Ship Shoal Area. Prepared by C & C Technologies, Inc. for GulfTerra Energy Partners, L.P. Report submitted to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Church, R., D. Warren, R. Cullimore, L. Johnston, W. Schroeder, W. Patterson, T. Shirley, M. Kilgour, N. Morris, and J. Moore. 2007. Archaeological and Biological Analysis of World War II Shipwrecks in the Gulf of Mexico: Artificial Reef Effect in Deep Water. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2007-015. 387 pp.
- Clarke, K. R. and R. M. Warwick (2001). Change in marine Communities: an approach to statistical analysis and interpretation. Plymouth, England, PRIMER-E.

- Colin P (1975) *The neon gobies* T. F. H. Publ., Neptune City, NJ.
- Cordes, E.E., Bergquist, D.C., Predmore, B.L., Dienes, P., Jones, C., Telesnicki, G., Fisher, C.R., 2006. Alternate unstable states: convergent paths of succession in hydrocarbon-seep tubeworm-associated communities. *Journal of Experimental Marine Biology and Ecology* 339, 159-176.
- Cordes EE, McGinley M, Podowski EL, Becker, EL, Lessard-Pilon S, Viada S, Fisher CR. (2008) Coral communities of the deep Gulf of Mexico. *Deep-Sea Research I*. 10.1016/j.dsr.2008.03.005
- Continental Shelf Associates, Inc. 2002. Deepwater Program: Bluewater Fishing and Deepwater OCS Activity, Interactions between the Fishing and Petroleum Industries in Deepwaters of the Gulf of Mexico. A Final Report for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Metairie, LA. OCS Study MMS-2002-78.
- Continental Shelf Associates International, Inc. 2007. Characterization of northern Gulf of Mexico deepwater hardbottom communities with emphasis on *Lophelia* coral. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Metairie, LA. OCS Study MMS-2007-44.
- Cowen RK, Paris CB, Srinivasan A (2006) Scaling of connectivity in marine populations. *Science* **311**, 522-527.
- Davies, P. S. (1989) Short-term growth measurements of corals using an accurate buoyant weighing technique *Mar. Biol.* Vol. 101: 389-395
- Dodds LA, Roberts JM, Taylor AC, Marubini F. 2007. Metabolic tolerance of the cold-water coral *Lophelia pertusa* (Scleractinia) to temperature and dissolved oxygen change. *Journal of Experimental Marine Biology and Ecology*. 349: 205-214.
- Eslinger, Kimberly. 2006. "Cultural Resources Assessment Report, "Medusa Prospect", Blocks 493-496, 537-540, 581-583, 626-627, and Vicinity, Mississippi Canyon Area." Prepared by C & C Technologies, Inc. for Murphy Exploration & Production Company. Report submitted to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Etnoyer, P. and J. Warrenchuk (2007). A catshark nursery in a deep gorgonian field in the Mississippi Canyon, Gulf of Mexico. *Bulletin of Marine Science* 81: 553-559.
- Formolo, M.J., Lyons, T.W., Zhang, C., Kelley, C., Sassen, R., Horita, J., Cole, D.R., 2004. Quantifying carbon sources in the formation of authigenic carbonates at gas hydrate sites in the Gulf of Mexico. *Chemical Geology* 205, 253-264.
- Fossa, J. H., Mortensen, P. B., Furevik, D. M. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. *Hydrobiologia* 471:1-12.
- Frederiksen R, Jensen A, and Westerberg H (1992) The distribution of the scleractinian coral *Lophelia pertusa* around the Faroe Islands and the relation to internal mixing. *Sarsia* 77:157-171.

- Freiwald, A., R. Henrich, J. Patzold. 1997. Anatomy of a deep-water coral reef mound from Stjærnsund, west Finnmark, northern Norway. In James, N. P., Clarke, J. A. D., (eds.), *Cool-Water Carbonates*. Society of Sedimentary Geologists (SEPM), Special Publication. 56:141-162.
- Freiwald, A., Henrich, R., Patzold, J. 1997. Anatomy of a deep-water coral reef mound from Stjærnsund, west Finnmark, northern Norway. In James, N. P., Clarke, J. A. D., eds., *Cool-Water Carbonates*. Society of Sedimentary Geologists (SEPM), Special Publication. 56:140-161.
- Freiwald A (1998) Geobiology of *Lophelia pertusa* (Scleractinia) reefs in the North Atlantic. Habilitation, University of Bremen.
- Freiwald A., J.B. Wilson & R. Henrich. (1999). Grounding Pleistocene icebergs shape recent deep-water coral reefs. *Sed. Geol.* 125: 1-8.
- Freiwald, A., V. Hühnerbach, B. Lindberg, J.B. Wilson, and J. Campbell. 2002. The Sula Ridge Complex, Norwegian Shelf. *Facies* 47:179-200.
- Gass SE, Roberts JM (2006) The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea: colony growth, recruitment and environmental controls on distribution. *Marine Pollution Bulletin* 52: 549-559
- Hall-Spencer, J., Allain, V., Fossa, J. H. 2002. Trawling damage to Northeast Atlantic ancient coral reefs. *Proc. R. Soc. Lond. B.* 269:507-511.
- Harper, D. E., P. B. Eyo and G. P. Scott. 2000. Updated golden crab fishery trends and production model analysis based on trip report logbook and trip interview data collection programs. Contribution Number PRD-99/00-12. NMFS Southeastern Fisheries Science Center. Miami, Florida.
- Hayes, J.A. 1990. Distribution, movement and impact of the corallivorous gastropod *Coralliophila abbreviata* (Lamarck) on a Panamanian patch reef. *J. Exp. Mar. Biol. Ecol.* 142:25-42.
- Heifetz J. (2002) Coral in Alaska: distribution, abundance, and species associations. *Hydrobiologia* 471: 19-28.
- Hellberg ME (2006) No variation and low synonymous substitution rates in coral mtDNA despite high nuclear variation. *Bmc Evolutionary Biology* 6. *Evolution* 53, 806-817.
- Henry, L-A., Roberts, J.M., 2007. Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep-Sea Res. I.* 54 (4), 654–672.
- Horrell, Christopher E. 2006. “500 Fathoms of Water: The Archaeological Remains of a Mid-Late Nineteenth Century Sailing Vessel in the Gulf of Mexico.” *Proceedings of the Society for Historical Archaeology Conference*, Sacramento, CA (January).
- Hovland, M., Thomsen, E. 1997. Cold-water corals- are they hydrocarbon seep related? *Mar. Geol.* 137: 159-164.

- Hovland, M., Mortensen, R. B., Brattegard, T., Strass, P., Rokoengen, K. 1998. Ahermatypic coral banks off mid-Norway: Evidence of a link with seepage of light hydrocarbons. *Palaaios* 13:189-200.
- Jensen A., and R. Frederiksen. 1992. The fauna associated with the bank-forming deepwater coral *Lophelia pertusa* (Scleractinia) on the Faroe shelf. *Sarsia* 77:53-69.
- Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins, 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research, report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.
- Krieger KJ, Wing BL (2002) Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. *Hydrobiologia* 471: 82-90
- Koslow J.A., K. Gowlett-Holmes, J.K. Lowry, T. O'Hara, G.C.B. Poore, and A. Williams. (2001). Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Mar. Ecol. Prog. Ser.* 213:111-125.
- Lockhart, F. D., W. J. Lindberg, N. J. Blake, R. B. Erdman, H. M. Perry, and R. S. Waller. 1990. Distributional differences and population similarities for two deep-sea crabs (Family Geryonidae) in the northeastern Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 2112-2122.
- Loya Y. and B. Rinkevich. (1980). Effects of oil pollution on coral reef communities. *Mar. Ecol. Prog. Ser.* 3: 167-180.
- Masson D.G, B.J. Bett, D.S.M. Billett, C.L. Jacobs, A.J. Wheeler and R.B. Wynn. (2003). The origin of deep-water, coral-topped mounds in the northern Rockall Trough, Northeast Atlantic. *Mar. Geol.* 194: 159-180.
- McEachran J.D. and J.D. Feuchhelm. (1998). *Fishes of the Gulf of Mexico*. University of Texas Press, Austin, TX. 1112 pp.
- Mienis, F., H. C. de Stigter, M. White, G. Dulneveldc, H. de Haas and T. C. E. van Weering (2007). "Hydrodynamic controls on cold-water coral growth and carbonate-mound development at the SW and SE rockall trough margin, NE Atlantic ocean." *Deep-Sea Research Part I-Oceanographic Research Papers* 54(9): 1655-1674.
- Mikkelsen N, Erlenkauser H, Killingley JS, and Berger WH (1982) Norwegian corals: radiocarbon and stable isotopes in *Lophelia pertusa*. *Boreas* 5:163-171.
- Moore, D. R., Bullis, H. R. 1960. A deep-water coral reef in the Gulf of Mexico. *Bulletin of Marine Science*. Vol. 10:125-128
- Mortensen, P. B., Hovland, M., Brattegard, T., Farestveit, R. 1995. Deep-water bioherms of the scleractinian coral *Lophelia pertusa* L. at 64° on the Norwegian shelf: structure and associated megafauna. *Sarsia*. 80:145-158.

- Mortensen, P. B., Rapp, H. T. 1998. Oxygen and carbon isotope ratios related to growth line patterns in skeletons of *Lophelia pertusa* (L) (Anthozoa, scleractinia): implications for determinations of linear extension rates. *Sarsia*. 83:433-446.
- Neigel JE (1997) A comparison of alternative strategies for estimating gene flow from genetic markers. *Annual Review of Ecology and Systematics* **28**, 105-128.
- Neumann AC, Kofoed JW, and Keller GH (1977) Lithoherms in the Straits of Florida. *Geology* 5:4-10.
- Penn K, Wu D, Eisen JA, Ward N (2005) Characterization of Bacterial Communities Associated with Deep-Sea Corals on Gulf of Alaska Seamounts. *App Env Microbiol* 72(2): 1680-1683
- Perry, H., R. Waller, C. Trigg, J. McBee, R. Erdman, and N. Blake. 1995. A note on bycatch associated with deepwater trapping of *Chaceon* in the northcentral Gulf of Mexico. *Gulf Research Reports* 9(2): 139-142.
- Peterson C.H., M.C. Kennicutt, R.H. Green, P. Montagna, D.E. Harper, E.N. Powell and P.F. Roscigno. (1996). Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: a perspective on long-term exposure in the Gulf of Mexico. *Can. J. Fish. Aquat. Sci.* 53: 2637-2654.
- Pritchard JK, Stephens M, Donnelly P (2000) Inference of population structure using multilocus genotype data. *Genetics* **155**, 945-959.
- Reed J.K. (2002). Comparison of deep-water reefs and lithoherms off southeastern USA. *Hydrobiologia* 471: 57-69.
- Reed, J. K., D. C. Weaver, and S. A. Pomponi. 2006. Habitat and fauna of deep-water *Lophelia pertusa* coral reefs off the southeastern U.S.: Blake Plateau, Straights of Florida, and Gulf of Mexico. *Bulletin of Marine Science* 78(2): 343-375.
- Reed, J. K., S. A. Pomponi, D. C. Weaver, C. K. Paull, and A. E. Wright. 2005. Deep-water sinkholes and bioherms of South Florida and the Pourtales Terrace- Habitat and Fauna. *Bulletin of Marine Science* 77(2):267-296.
- Risk M.J., J.M. Heikoop, M.G. Snow, R. Beukens. (2002). Lifespans and growth patterns of two deep-sea corals: *Primnoa resedaeformis* and *Desmophyllum cristagalli*. *Hydrobiologia* 471: 125-131.
- Ritger, S., B. Carson, and E. Suess, 1987, Methane-driven authigenic carbonates formed by subduction-induced pore-water expulsion along the Oregon/Washington margin: Geological Society of America Bulletin, v. 98, p. 147-156.
- Roberts, H.H. and P. Aharon, 1994, Hydrocarbon-derived carbonate buildups of the northern Gulf of Mexico continental slope: A review of submersible investigations: *Geo-Marine Letters*, v. 14, p. 135-148.
- Roberts, H.H, B.A. Hardage, W.W. Shedd, and J. Hunt, Jr., 2006, Seafloor reflectivity – An important seismic property for interpreting fluid/gas expulsion geology and the presence of gas hydrate: *The Leading Edge*, Society of Exploration Geophysicists, v. 25, p. 620-628.

- Roberts HH, Fisher CR, Bernard B, Brooks JM, Bright M, Carney RS, Cordes EE, Goehring L, Hourdez S, Hunt Jr. JL, Joye SM, MacDonald IR, Morrison C, Niemann H, Potter J, Samarkin V, Shedd W, Telesnicki G, Becker EL, Bernier M, Bowles M, Kupehik M, Lessard-Pilon S, Petersen C, Petersen J. (2007) *ALVIN* explores the deep northern Gulf of Mexico slope. *EOS* 88: 341-342.
- Roberts JM, and Anderson RM (2002) A new laboratory method for monitoring deep-water coral polyp behaviour. *Hydrobiologia* 471:143-148.
- Roberts J.M., D. Long, J.B. Wilson, P.B. Mortensen, J.D. Gage. (2003). The cold-water coral *Lophelia pertusa* (Scleractinia) and enigmatic seabed mounds along the north-east Atlantic margin: are they related? *Mar. Poll. Bull.* 46: 7-20.
- Roberts, J. M. (2005). "Reef-aggregating behaviour by symbiotic eunicid polychaetes from cold-water corals: do worms assemble reefs?" *Journal of the Marine Biological Association of the United Kingdom* 85(4): 813-819.
- Roberts, J.M., Wheeler, A.J., Freiwald, A., 2006. Reefs of the deep: The biology and geology of cold-water coral ecosystems. *Science* 312, 543-547.
- Rogers, A. D. 1999. The biology of *Lophelia pertusa* (Linnaeus 1758) and other deep-water reef forming corals and impacts from human activities. *Int. Rev. Hydrobiol.* 84:315-406.
- Rosenberg NA, Burke T, Elo K, *et al.* (2001) Empirical evaluation of genetic clustering methods using multilocus genotypes from 20 chicken breeds. *Genetics* **159**, 699-713.
- Ross, S. W. and A. M. Quattrini. 2007. The fish fauna associated with deep coral banks off the southeastern United States. *Deep-Sea Research I* 54: 975-1007.
- Sabater MG and Yap HT (2002) Growth and survival of coral transplants with and without electrochemical deposition of CaCO₃. *Journal of Experimental Marine Biology and Ecology* 272: 131-146.
- Schroeder, W. W. 2002. Observations of *Lophelia pertusa* and the surficial geology at a deep-water site in the northeastern Gulf of Mexico. *Hydrobiologia* 471:29-33.
- Sheriff, R.E, 2002, *Encyclopedic Dictionary of Applied Geophysics*, fourth Addition: Society of Exploration Geophysicists, Tulsa, Oklahoma, 429 p.
- Starck WAI, Colin PL (1978) *Gramma linki*: a new species of grammid fish from the tropical western Atlantic. *Bull Mar Sci* **28**, 146-152.
- Sulak, K.J., Brooks, R.A., Luke, K.E., Norem, A.D., Randall, M., Quaid, A.J., Yeargin, G.E., Miller, J.M., Harden, W.M., Caruso, J.H., Ross, S.W., 2007. Demersal fishes associated with *Lophelia pertusa* coral and hard-substrate biotopes on the continental slope, northern Gulf of Mexico. *Bulletin of Marine Science*. 81:65-92
- Taylor MS, Hellberg ME (2003) Genetic evidence for local retention of pelagic larvae in a Caribbean reef fish. *Science* **299**, 107-109.

- Tissot, B. N., M. M. Yoklavich, M. S. Love, k. York, and M. Amend. 2006. Structure-forming invertebrates as components of benthic habitat on deep banks off southern California with special reference to deep sea corals. *Fish. Bull.* 104: 167–181
- Turley, C., Roberts, J.M. & Guinotte, J.J. (2007) Corals in deep water: Will the unseen hand of ocean acidification destroy cold water ecosystems? *Coral Reefs* 26: 445-448.
- Vardaro, M., I. R. MacDonald, L. C. Bender and N. L. Guinasso Jr. (2005). "Dynamic biological and physical processes observed at a gas hydrate outcropping on the continental slope of the Gulf of Mexico." *Geo-Marine Letters* 26(1): 6-15.
- Wakeley JW (2004) Metapopulation models for historical inference. *Molecular Ecology* **13**, 865-875.
- Waller, RG & Tyler PA. (2005) The reproductive biology of two deep-sea, reef-building scleractinians from the NE Atlantic Ocean. *Coral Reefs*, 24(3), 514-522.
- Wang JL, Whitlock MC (2003) Estimating effective population size and migration rates from genetic samples over space and time. *Genetics* **163**, 429-446.
- Warren, Daniel. 2006a. Archaeological assessment Report, “Shallow Coulomb” Prospect, Block 701 and Vicinity, Mississippi Canyon Area. Prepared by C & C Technologies, Inc. for Shell Exploration and Production. Report submitted to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Warren, Daniel. 2006b. Archaeological Assessment Report, Blocks 1007 and 1008, Ewing Banks Area and Blocks 37 and 38, Green Canyon Area. Prepared by C & C Technologies, Inc. for ATP Oil and Gas. Report submitted to the U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Wiggins, Melanie. 1995. Torpedoes in the Gulf, Galveston and the U-boats, 1942-1943. Texas A&M Press: College Station, TX.
- Wilson JB (1979b) Patch development of the deep-water coral *Lophelia pertusa* (L.) on Rockall Bank. *J. Mar. Biol. Ass. U.K.* 59:165-177.
- Yoklavich, M. and Love, M. (2005). Christmas tree corals: a new species discovered off southern California. *Current, the Journal of Marine Education*, **21**, 27-30.